JANUARY 2006 ACCURACY STATUS

FOR

NASA BUILDINGS-RELATED CLIMATE PARAMETERS

OVER THE GLOBE

by

Charles H. Whitlock, William S. Chandler, James M. Hoell, David J. Westberg
Science Applications International Corporation, Hampton, VA, 23666-5845

Taiping Zhang
Analytical Services and Materials, Inc., Hampton, VA 23666-5845

Paul W. Stackhouse Jr.
Mail Stop 420, NASA Langley Research Center, Hampton, VA 23681-2199

A Special Report for the ASHRAE Technical Committee 4.2 on Climatic Information
ASHRAE 2006 Winter Meeting and EXPO
Chicago, IL. January 21-25

Sponsored
by the
NASA Applied Sciences Program, Earth-Sun System Division

INTRODUCTION

Preliminary buildings climatology maps for the globe have been constructed using NASA Release 5.1 Surface meteorology and Solar Energy (SSE) data. Release 5.1 SSE uses Release 2 Surface Radiation Budget (SRB) radiation data (1-deg spatial resolution), Version 1 Goddard Earth Observation System (GEOS-1) reanalysis meteorology data (2.5 x 2 deg original spatial resolution), and NASA/NOAA Global Precipitation Climatology Project (GPCP) precipitation data (2.5 x 2.5 deg original spatial resolution) as inputs. SRB is based on geostationary satellite cloud information. GPCP is a merged analysis that combines precipitation estimates from low-orbit satellite microwave data, geosynchronous orbit infrared data, and over 40,000 surface rain gauge observations. Bi-linear interpolation techniques were used to provide estimates of values for both GEOS-1 and GPCP data in the Release 5.1 SSE on a global 1-degree by 1-degree latitude-longitude grid. The purpose of this document is to summarize validation studies of the SSE release 5.1 10-year data set, and to provide the resulting estimates of accuracy for monthly averages of insolation, temperature, surface pressure, relative humidity, and wind data.

Longwave (LW) surface radiation values are planned in future SSE releases. New 22-yr GEOS-4 meteorology data have also been recently been received. The GEOS-4 data have 1.25 degree by 1 degree spatial resolution and should provide more accurate buildings climate maps in the future. The LW and preliminary GEOS-4 accuracy information will also be reviewed in this document.

BACKGROUND INFORMATION

The present NASA buildings-related climate products were initiated in 1983 when NASA partnered with the World Meteorology Organization (WMO) to investigate possibilities for obtaining accurate climate-related meteorological parameters from geostationary satellite data. Those satellites had primarily been designed for qualitative cloud detection and generally were not calibrated in a quantitative manner. In-flight satellite calibration procedures were developed, and an international team compared and selected the most accurate methods for estimating both shortwave (SW) and LW radiation below the clouds at the Earth’s surface over the globe. Those methods were then used by NASA to generate a SRB data set which was released to the international climate science community in the early 1990s. The data were in chronological order and were formatted in one of the advanced computer codes (hdf) because of file sizes. The original SRB data set has been improved and a more accurate version (Release 2) is now being provided to the climate science community.

Following the initial release of the SRB data set, the DOE National Renewable Energy Laboratory (NREL) requested that the original SRB data be converted to specific parameters for the renewable energy community and synthesized to monthly-average values. Those data were prepared and delivered to NREL by NASA in the mid-nineties. NASA began receiving requests for the data with added parameters from domestic and foreign government agencies and businesses as well as contractors for the United Nations (UN). NASA management decided to reformat the science-based SRB data to provide commercially-requested parameters in a new data set designated as SSE. Moreover, parameters available through SSE were made publicly available via an on-line data portal. As the science-based SRB data sets are improved and requests for new parameters are received, updated versions of the SSE are released. The SSE data sets could not have been completed without the assistance of a number of partners at no cost to NASA. Please see the Partners and Performance section at the bottom of the SSE home page (http://eosweb.larc.nasa.gov/sse/) for additional information.

SSE RELEASE 5.1 ACCURACY ESTIMATES

This section provides estimates of the levels of uncertainty for insolation, temperature, surface pressure, relative humidity, and wind through comparisons with ground-site measurement data. Unless otherwise noted, all uncertainty values are for monthly-average values. We note here that the wind data are not corrected to the actual height and vegetation of the measurement site within the 1-degree cell because detailed site information was generally not available.

Ground site data were obtained from:

Table 1. Sources of Ground Site Measurement Data for Validation of SSE Release 5.1

Organization	Ground Site Data Set
World Radiation Data Center	* World Radiation Data Center (1195-site WRDC, pre-1993)
DOE National Renewable Energy Research Laboratory	* Saudi Arabia pyroheliometer-type site (1999) * Several U.S. Universities (1985-1989)
Natural Resources Canada	* RETScreen Weather Database (1000+ sites, 1964-1998)
Swiss Federal Institute of Technology (ETHZ)	* Global Energy Budget Archive (717 high-quality GEBA sites, Pre-1994) * Baseline Surface Radiation Network (sites for 1992 - 2000)
DOE Pacific Northwest National Laboratory	* Atmospheric Research Measurement Program (Two ARM pyroheliometer-type sites in Oklahoma and Papua New Guinea, 1998 and 1999)
NOAA Climate Monitoring and Dynamics Laboratory	* CMDL pyroheliometer-type sites (two in Colorado and Kwajalein ,1992; and four in Bermuda, Kwajalein, Samoa and Alaska, 1999 and 2000) * Four SURFRAD pyroheliometer-type sites in Nevada, Mississippi, Pennsylvania, and Colorado (1999)
NASA Langley Research Center	* Clouds and the Earth's Radiant Energy System (one CERES pyroheliometer-type lighthouse site in Virginia , 2000)
The State University of New York at Albany's Atmospheric Science Research Center	* Four pyroheliometer-type sites in New York, New Mexico, Florida, and Kansas, 1999
University of Texas	*Texas Solar Radiation Data Base (four pyroheliometer-type TSRD sites, 1999)

Note: All pyroheliometer-type sites utilized had horizontal-surface insolation measurements. Most sites also had separate horizontal-surface diffuse measurements.

While it is generally considered that quality ground-site measured data are more accurate than satellite-derived values, measurement uncertainties from calibration drift, operational uncertainties, or data gaps are unknown for the above ground-site data sets. In 1989, the World Climate Research Program (WCRP) estimated that most routine-operation surface radiation ground sites had "end-to-end" radiation measurement uncertainties from 6 to 12%. Specialized high quality research sites are more accurate by a factor of two. The uncertainties of temperature, humidity, precipitation, and winds were not estimated as part of that study.

NASA compared the SSE release 5.1 1-degree by 1-degree cell-average radiation estimates with ground-site data on a global basis, and Natural Resources Canada (NRCan) performed a similar analysis for 200 sites in 7 continental regions that are considered typical locations for future renewable energy systems. The 200 sites analysis was conducted because it was believed that very-high latitude uncertainty statistics may be unrealistic from a practical-use viewpoint.

Table 2. Estimated Monthly Uncertainty for Release 5.1 SSE

Parameter	Method	RMS (Bias)
Horizontal Insolation	* SSE satellite-based Pinker	13 to 16% (+ 0.7 to -2%)
Horizontal Diffuse Radiation	* SSE/Erbs et al. correlation	~ 18% (+ 4%)
	* SSE/Extended Page (74 reference sites)	~ 20% (+ 3%)
Direct Normal Radiation	* SSE/RETScreen-type (hourly angular conversion)	~ 15% (- 9%)
	* SSE/Extended Page (empirical Staylor angular conversion)	~ 24% (+ 2%)
Flat, Rough Grass Wind (10-m height)	* Documented 10-m height airport sites	1.3 m/s (-0.2 m/s)
	* Unknown-height airport sites	1.3 m/s (0.0 m/s)
Air Temperature, K (10-m height)	* Global sites $\leq$ 243K	3.2% (NA)
	* Global sites $\geq$ 263K	1.1% (NA)
	* Global sites between 243K and 263K	Linear variation
	* 200 potential renewable energy sites in 7 continental regions	1.2% (NA)
Heating Design Temperature, K	* 200 potential renewable energy sites	1.3% (NA)
Cooling Design Temperature, K	* 200 potential renewable energy sites	1.4% (NA)
Summer Mean Daily Temperature Range, K	* 200 potential renewable energy sites	0.9% (NA)
Heating Degree-Days < 18-deg C, deg-days	* 200 potential renewable energy sites	15% (NA)
Relative Humidity, %	* Global	18.5% of mean
	* 200 potential renewable energy sites	10% of mean
Surface Pressure, kPa	* Global	3.8% (NA)
	* 200 potential renewable energy sites	2.4% (NA)

Radiance data on tilted panels or walls were not generally available. Three SSE tilted-panel methodologies were verified against calculated values for isotropic and non-isotropic skies by comparison with RETScreen CD-ROM software and the National Renewable Energy Laboratory (NREL) Solar Radiation Data Base (SRDB).

Additional information on the methods used in SSE release 5.1 can be obtained from the Methodology Section at http://eosweb.larc.nasa.gov/sse/.

The uncertainty in the GPCP precipitation data was not estimated by the SSE team. A recent article by the GPCP team (http://www.icess.ucsb.edu/gem/Adler.et.al2003.J.Hydrology.GPCP.monthly.pdf) indicates that monthly bias values over land range between +9 and -5 percent and values over the Pacific Atolls may have biases equal to -16%.

Figure 1 shows scatter charts for all-sky SW radiation incident on a horizontal surface. Measured values are on the horizontal axis, and SSE values are on the vertical axis. Monthly values are the result of summing 24-hour daily values. Three-hourly monthly values are the result of first summing 3-hourly values at a specific time over the month to obtain a monthly-average diurnal cycle. Monthly-average diurnal values are then summed to obtain 3-hourly monthly. As expected, 3-hourly values show more scatter than daily or monthly comparisons because of the 1-deg cell size of the SRB and SSE radiation data. Figure 2 shows similar scatter plots for diffuse SW irradiance on a horizontal surface at the Earth's surface for the two methods used in Release 5.1. Figure 3 shows a similar comparison for Direct Normal Radiation perpendicular to the solar beam. Figures 4 and 5 show tilted wall or panel SSE values compared with other data that we could obtain. In general, satellite-based Release 5.1 SSE radiation estimates are in line with other estimated or measured monthly data.

Cell-size-interpolated 10-yr averaged GEOS-1 reanalysis meteorology show varying agreement relative to 30-yr averaged surface measurements as shown in Figures 6, 7, and 8. Monthly-averaged temperatures, as shown in Figure 7, agree well with observations giving an RMS difference of just over 1 %. The bottom of Table 2 above gives another perspective of the GEOS-1 temperature inaccuracies in per cent Kelvin. Note that Heating Degree-Days had 15% RMS based on Kelvin temperatures. It should be noted that temperature RMS is lower on Figure 7 than the value given in Table 2. Figure 7 is for the whole globe (1.03 % K), and Table 2 is for only 200 potential renewable energy sites (1.2 % K). Figures 6, 7, and 8 indicate that monthly winds, air pressure, and humidity do not agree as well as other parameters. However, there is some question about the accuracy of some ground-site wind data used in this comparison. Nevertheless, these uncertainties should be weighted in any design analysis that incorporates the data sets discussed here.

Release 5.1 SSE values were used to map several weather parameters of interest to the buildings industry. Figure 9 global precipitations are based on interpolated 1-deg GPCP data. Figure 10 compares GPCP estimates with 1961-1990 values from the National Atlas. Figures 11 and 12 degree-day values are based on interpolated 1-deg GEOS-1 monthly temperature values. Figures 13 and 14 are preliminary climate estimates based on Briggs et al. methodologies (http://www.energycodes.gov) using figures 9, 11, and 12 data as inputs.

NEW 1-DEG LONGWAVE RADIATION AND GEOS-4 TEMPERATURE ACCURACIES

Figure 15 shows a scatter plot of BSRN ground site observations of LW surface radiance vs estimates from a future new release of the SRB archive. Parameters reflecting good agreement between the two data sets are given in the upper left corner of the chart. The next SSE release will also use the new SRB data.

GEOS-4 near-surface temperatures are presently being compared with measured data from approximately 50 sites in North America. Figures 16 through 20 show daily integrated temperature scatter charts for flat-terrain types of locations that often have snow in the winter. Figure 16 shows average daily temperature comparisons for 2 sites in a large city (Montreal, Canada). Figures 17, 18, and 19 show average, maximum, and minimum daily temperatures for 10 ground sites in North Dakota compared with GEOS-4 near-surface values. Figure 20 compares dew point temperature values for the 10 locations in North Dakota. These results suggest that GEOS-4 flat-terrain temperature data may be sufficient for many users.

Initial comparisons of the GEOS-4 temperatures and ground observations in the mountain regions (eg. U.S. Pacific Northwest) indicated a bias between the data set which was dependent upon the difference in elevation of the ground site and the average elevation of the GEOS-4 1-degree x 1-degree cell. The bias increased as the elevation difference increased. Correction of the GEOS-4 temperatures based on a temperature lapse rate was found to significantly reduce the bias. Figures 21 and 22 show the effect of that correction in a 1-deg cell in Idaho. That cell had three sites that were significantly lower in elevation than the average cell height for which GEOS-4 provides temperature values. Uncorrected GEOS-4 (purple symbols) tended to have lower temperatures because of the higher elevation of the cell. For these two charts, GEOS-4 values have been lapse-rate adjusted to the average elevation of the three sites (green symbols). Figure 21 suggests that the lapse rate correction is reasonably accurate for maximum daily temperatures. Figure 22 indicates that the lapse-rate correction is not quite as accurate for minimum daily temperatures.

Accuracy results to date from approximately 50 sites are summarized in figures 23 and 24. All data has been lapse rate corrected when cell and ground site elevations are significantly different. Figure 23 is for 1991 and 1998 daily average data. The top chart in figure 24 shows that maximum daily temperatures have about the same level of uncertainty as average temperatures. The bottom chart shows minimum daily temperatures have more scatter than both the maximum and average data. In general, all three types of temperature have additional scatter when site temperatures get below freezing. It is not known whether the problem is with the GEOS-4 values or with ground site values.

CONCLUDING REMARKS

This report was prepared to quickly provide an in-depth view of presently-known accuracies and issues associated with both the present NASA Release 5.1 SSE data and soon to be included LW surface radiation and GEOS-4 meteorology results. Although high quality long-term ground site information is always preferred at specific locations, the data sets compiled in SSE have been shown to be significantly accurate to provide data quantity estimates where no ground site information id available. The data sets have been downloaded by a large number of organizations for a variety of applications. See the Partners and Performance section at the bottom of the SSE home page (http://eosweb.larc.nasa.gov/sse/) for additional information.

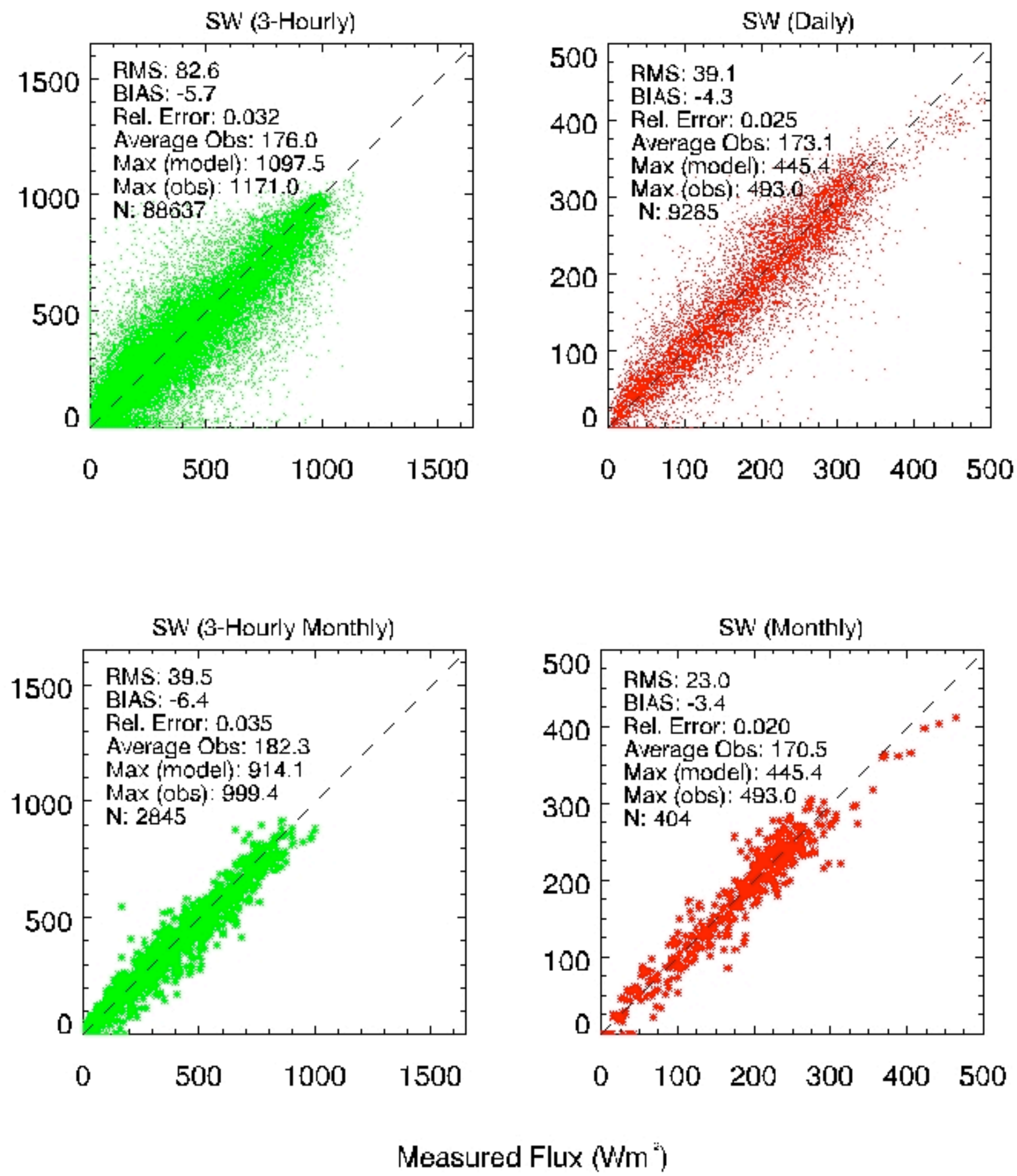
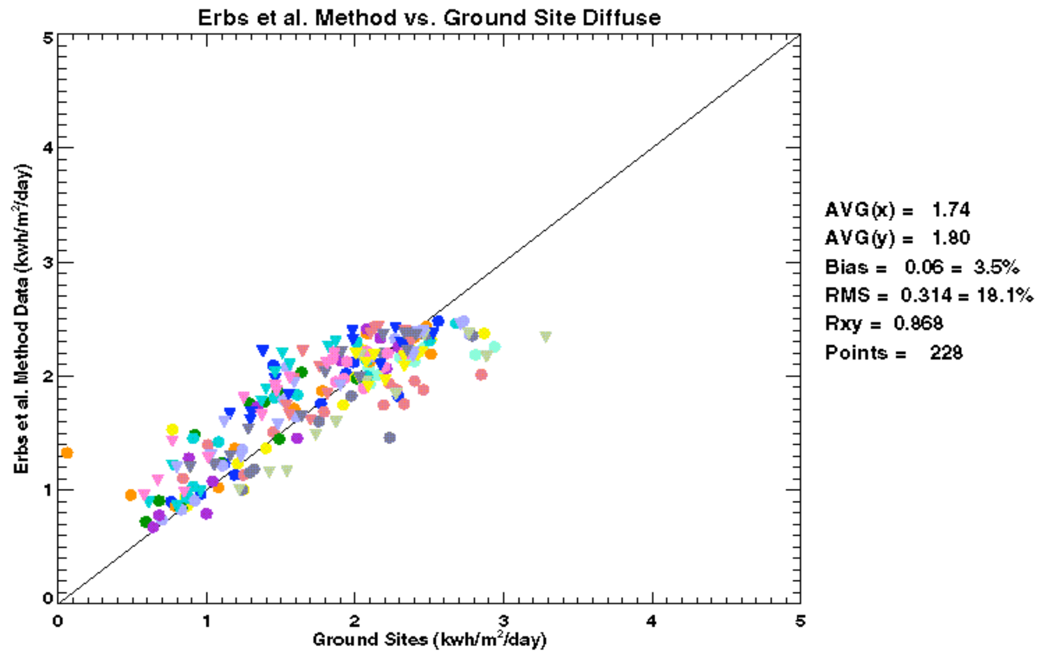


Figure 1. Insolation accuracy for 1992-1995 high-quality BSRN sites available from the Swiss Federal Institute of Technology.



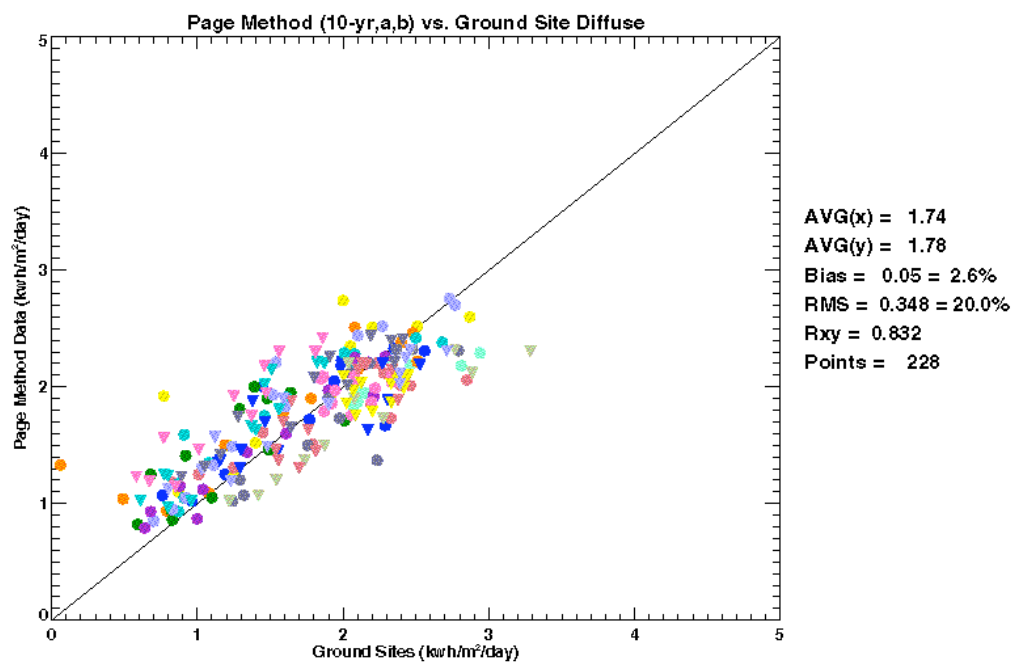


Figure 2. Statistical comparison of Erbs et al. method with extended Page 10-yr method for diffuse surface solar radiation in Release 5.1 SSE.

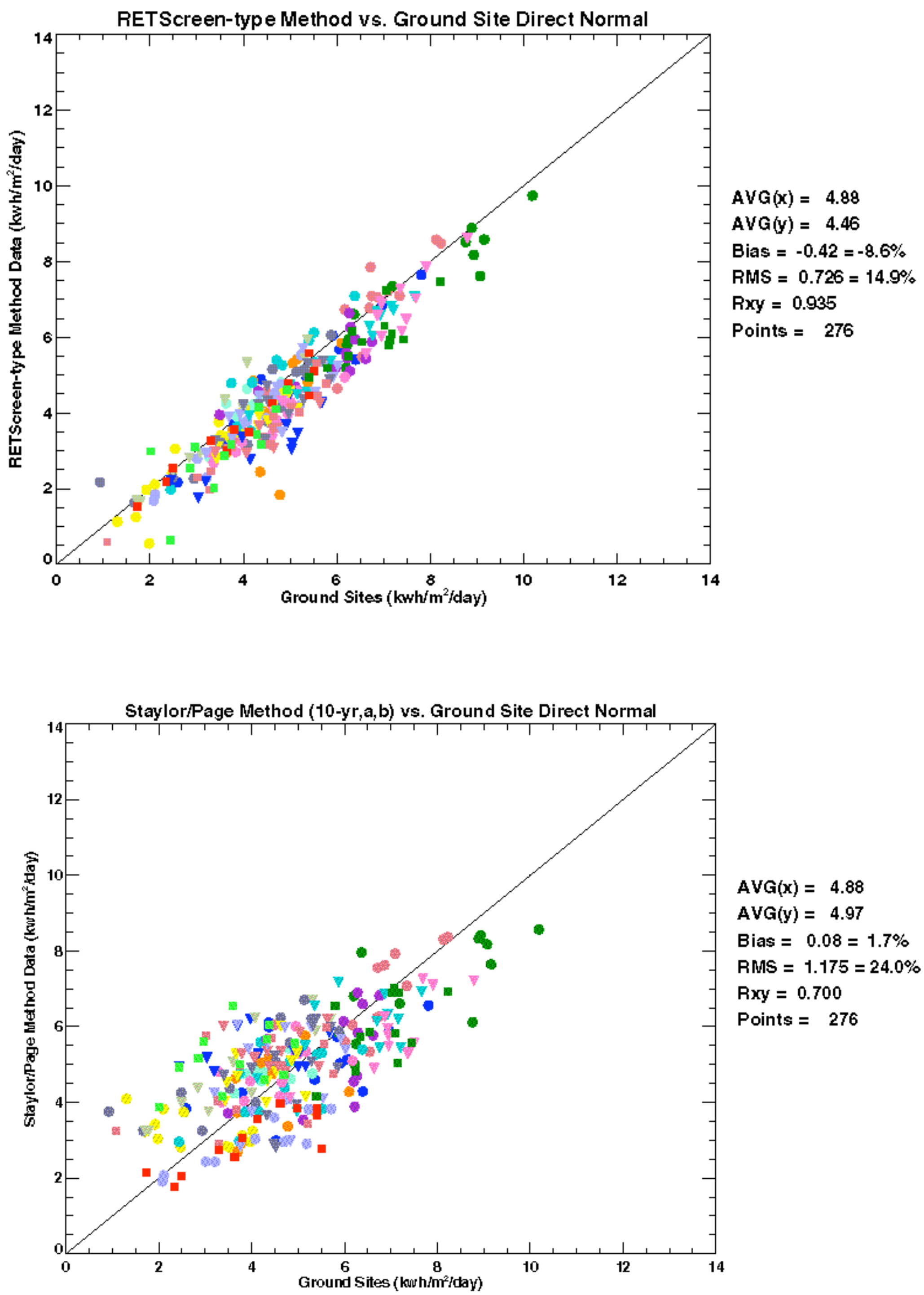


Figure 3. Statistical comparison of RETScreen-type method with extended Page 10-yr method for surface direct normal radiation in Release 5.1 SSE.

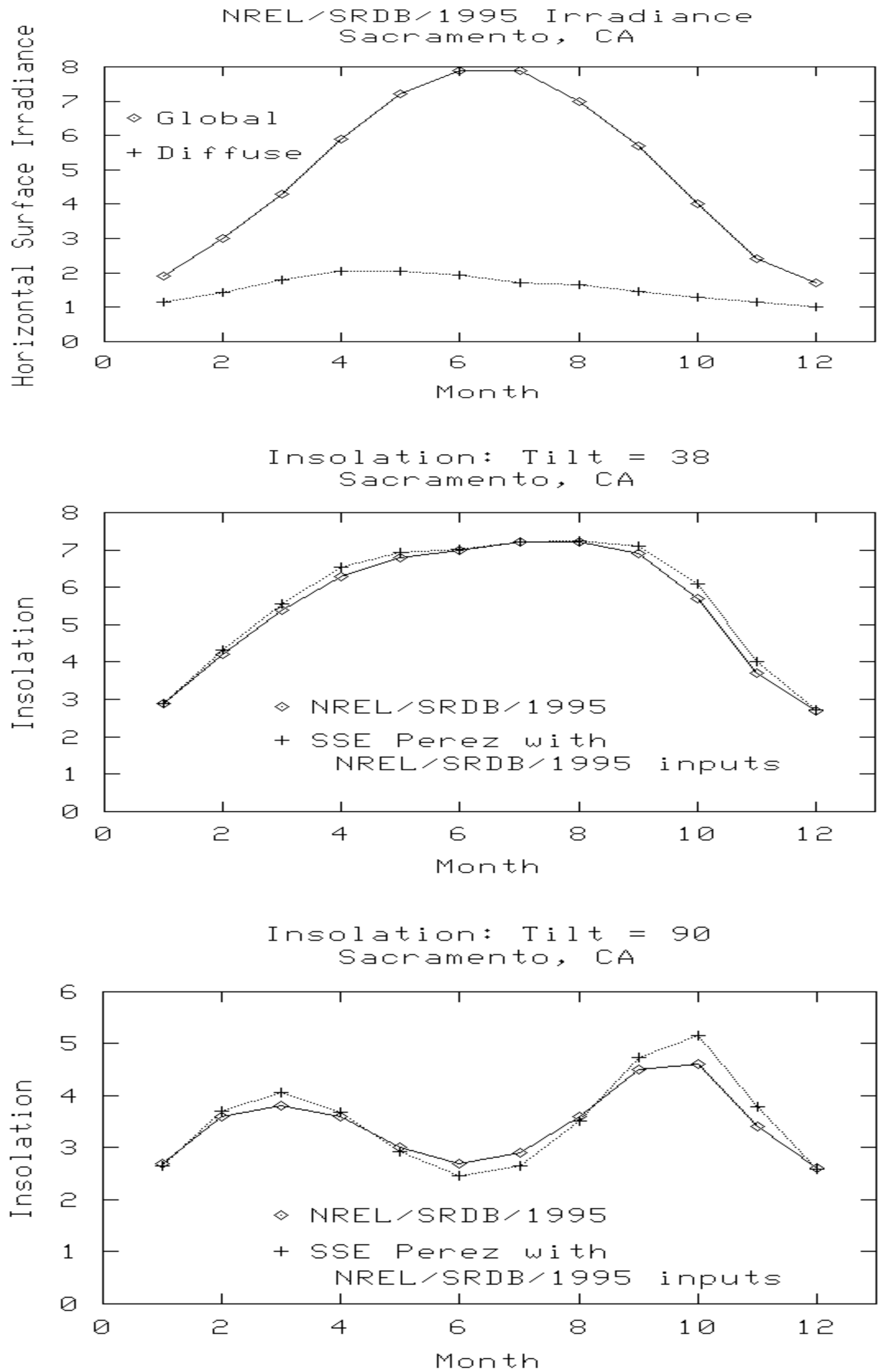


Figure 4. Comparison of Release 5.1 SSE Perez method with NREL Perez results for tilted walls or panels.

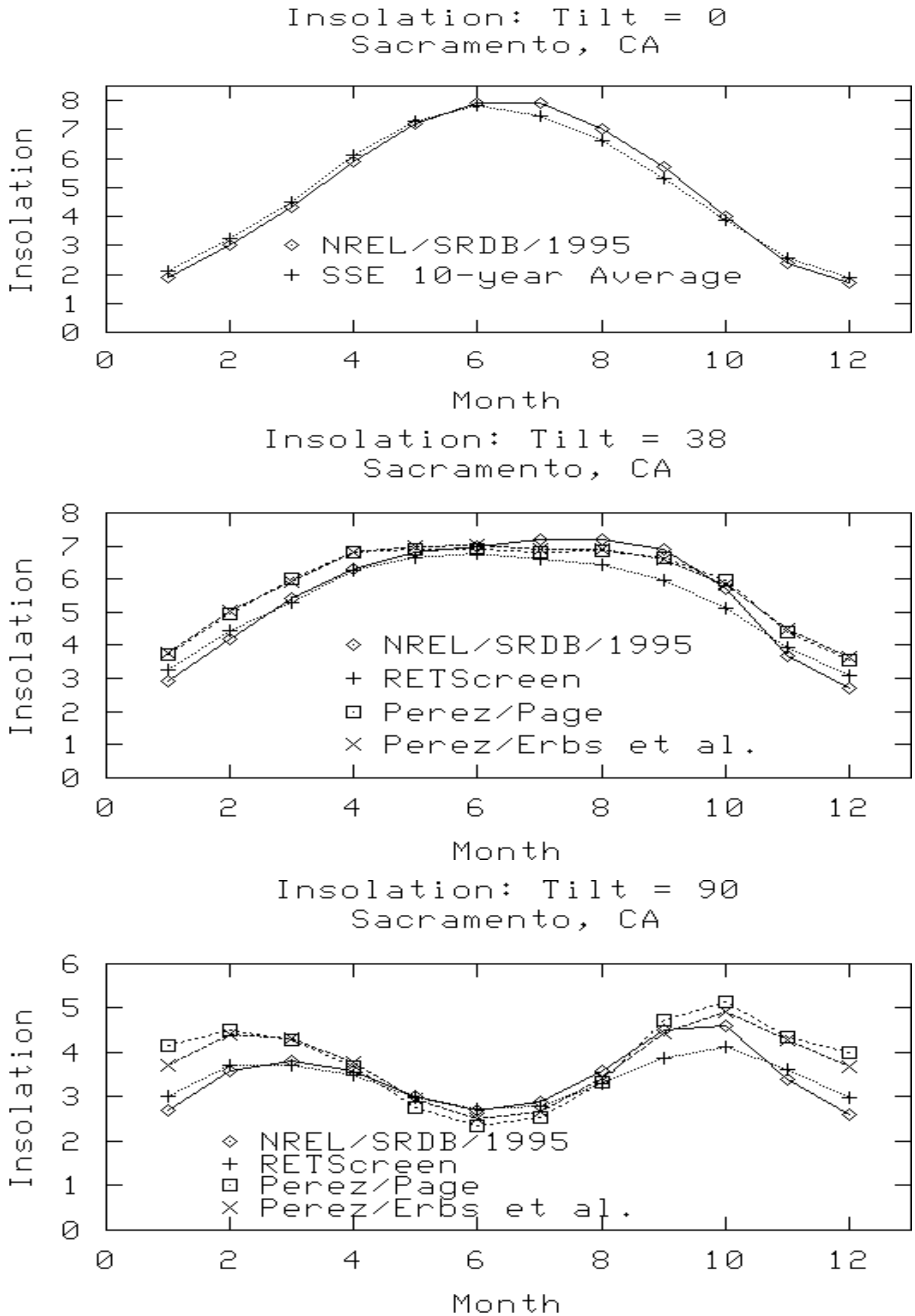


Figure 5. 10-yr average tilt results for two Release 5.1 SSE methods (e.g. Perez/Page and Perez/Erbs et al.) compared with NREL and RETScreen values.

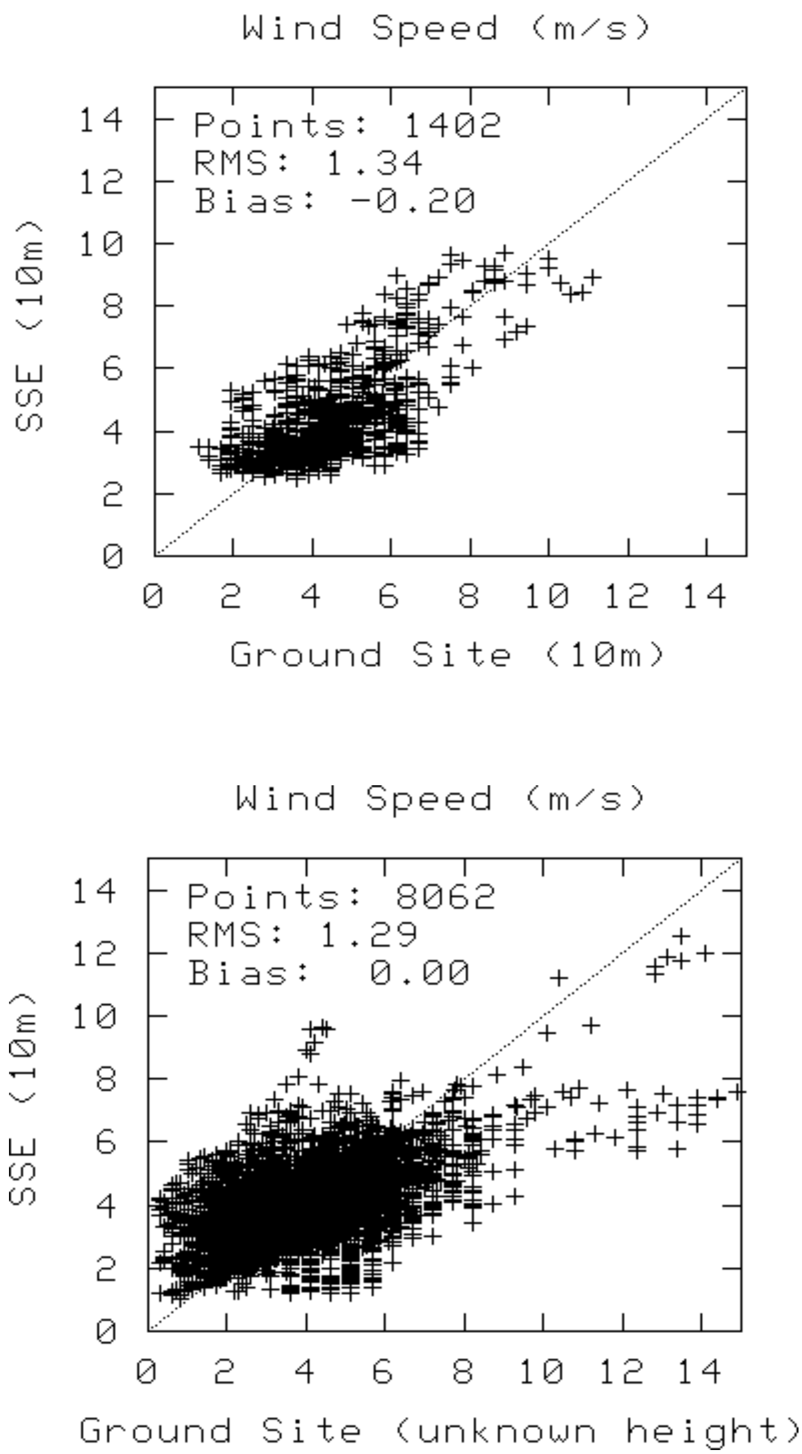


Figure 6. Comparison Release 5.1 SSE GEOS-1 10-m wind speed with 30-yr RETScreen site data.

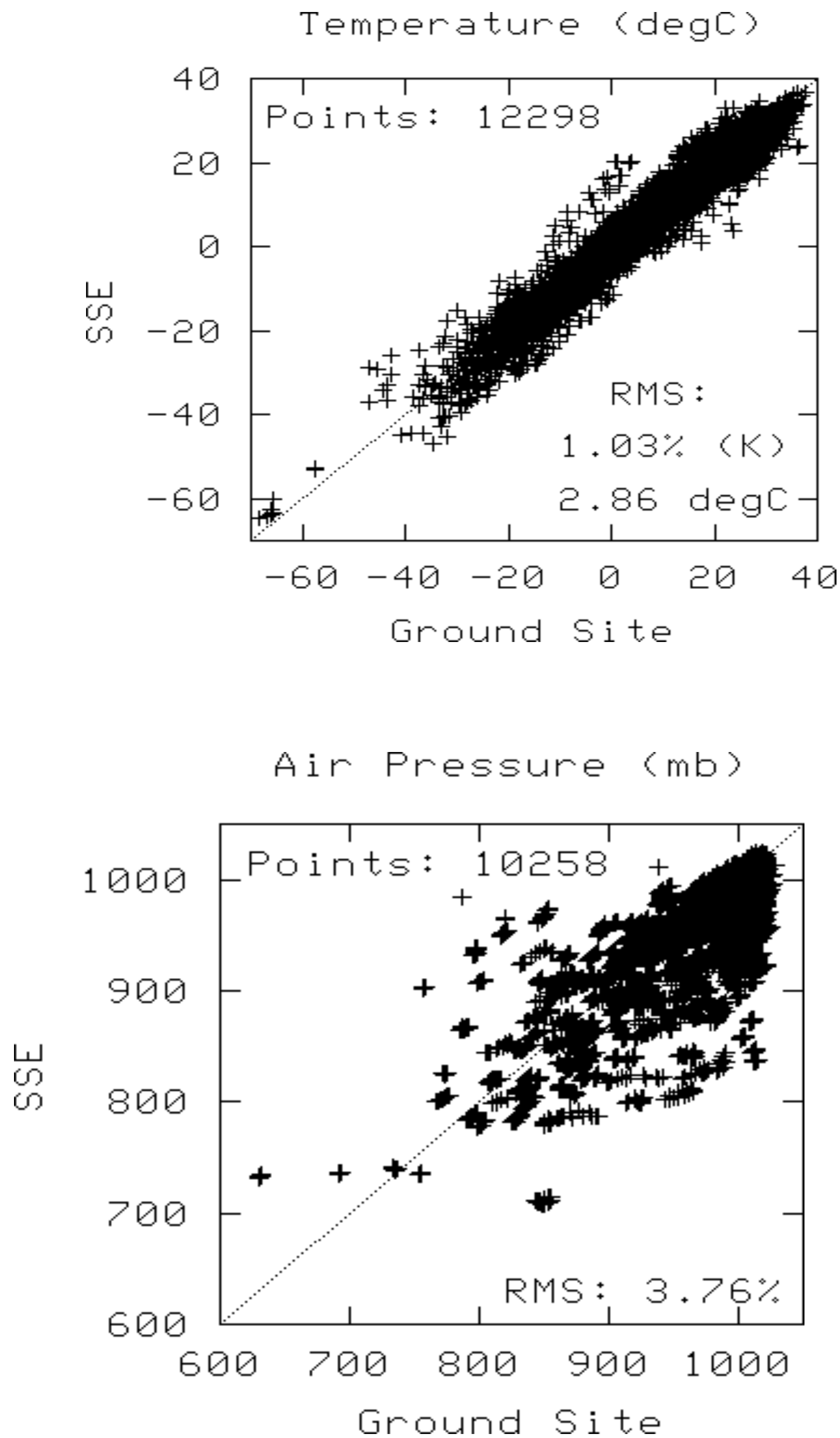


Figure 7. Comparison of 10-yr Release 5.1 SSE GEOS-1 10-m monthly temperature and pressure with 30-yr RETScreen site data .

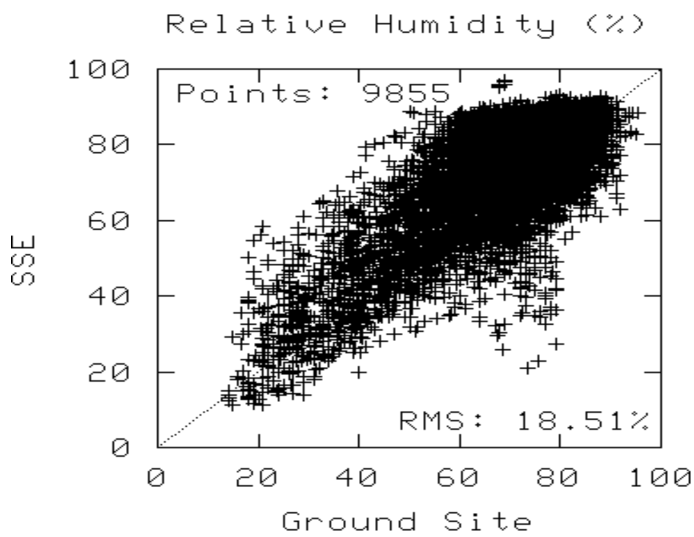


Figure 8. Comparison of 10-yr Release 5.1 SSE GEOS-1 10-m relative humidity with 30-yr RETScreen site data.

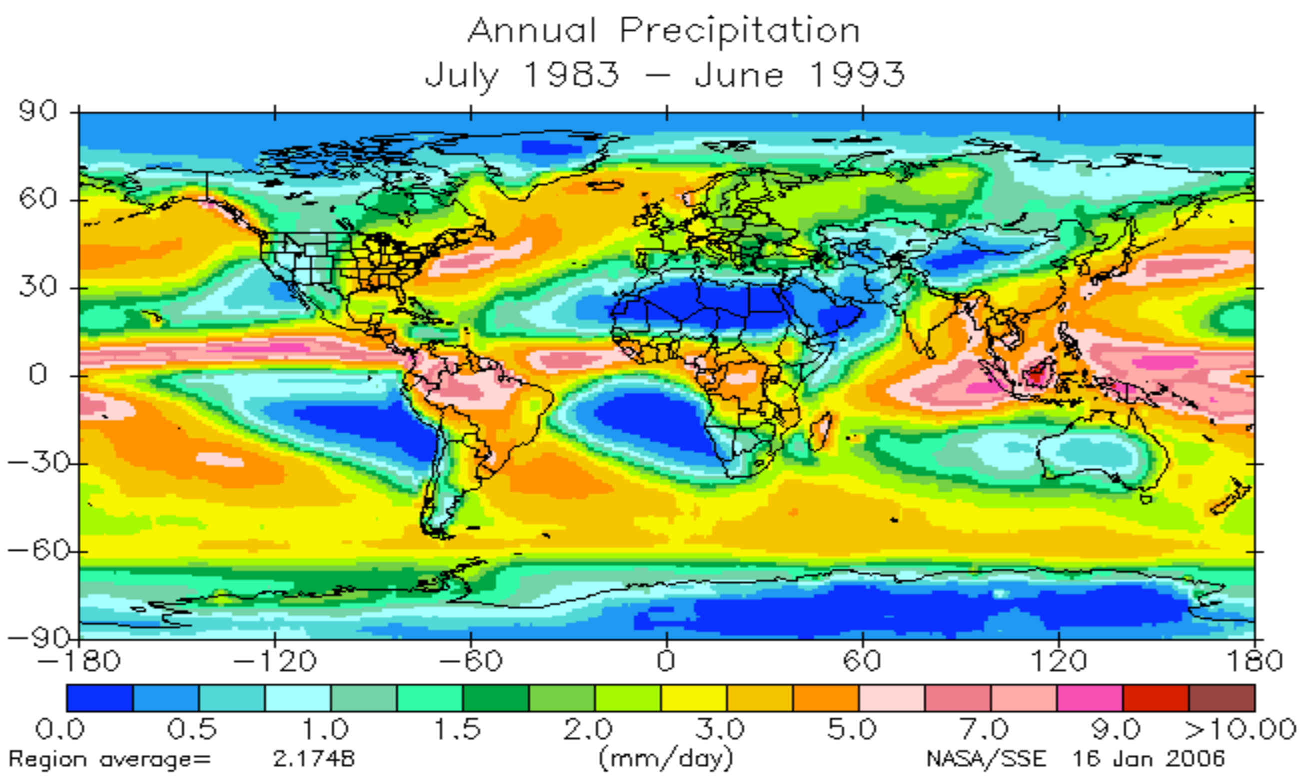
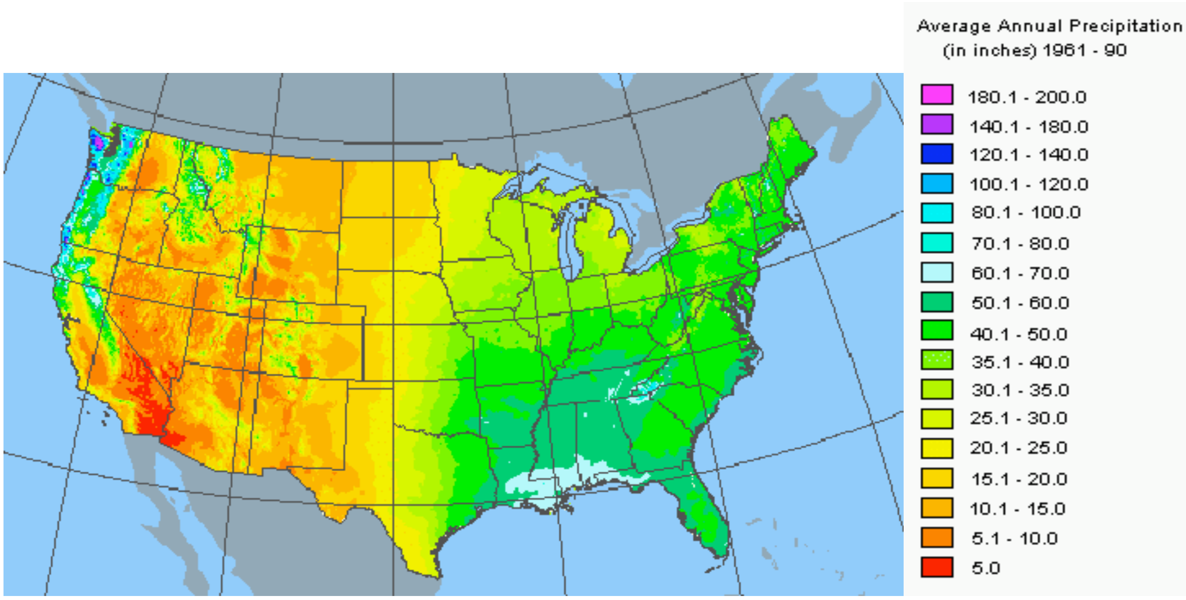


Figure 9. Release 5.1 SSE GPCP annual precipitation.

IMAGE FROM THE NATIONAL ATLAS OF THE UNITED STATES



RELEASE 5.1 SSE DATA FROM GPCP

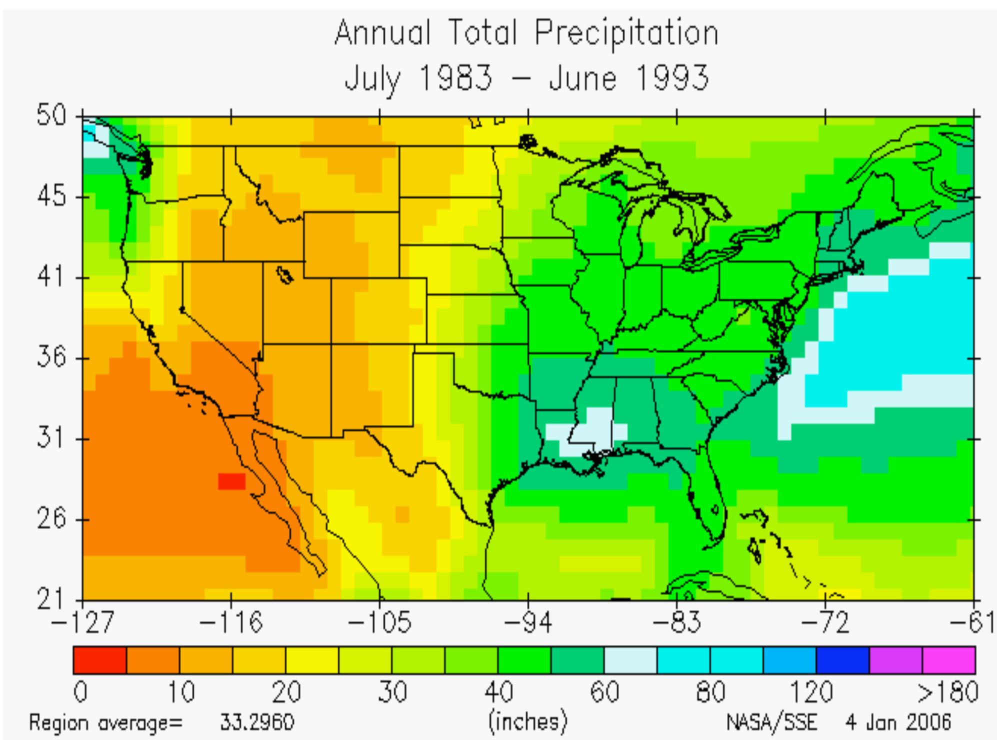


Figure 10. Comparison of National Atlas and GPCP precipitation data for the U.S.

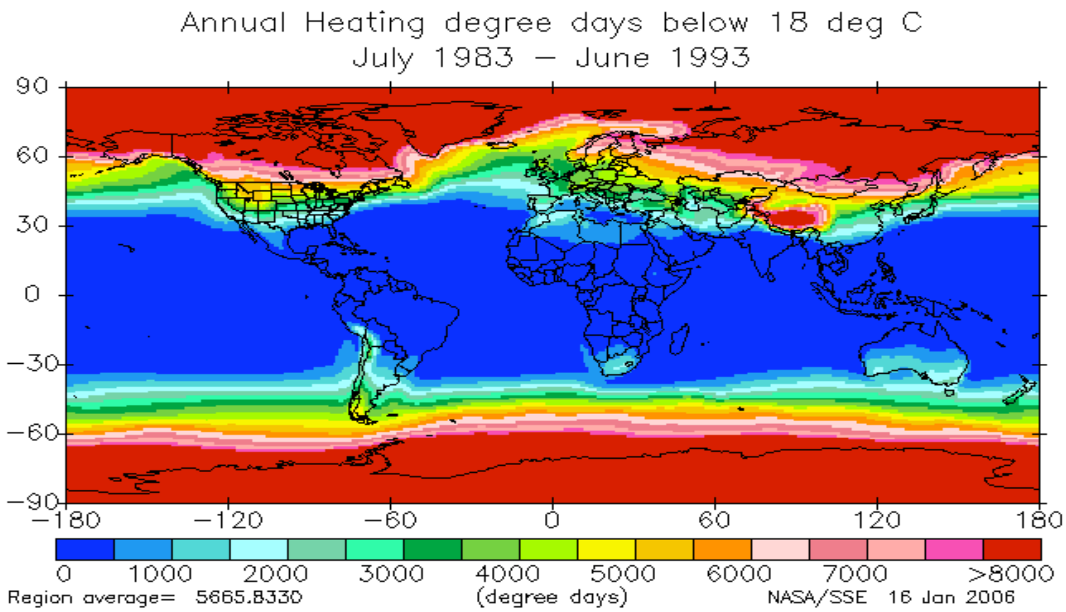


Figure 11. Release 5.1 SSE annual heating degree days.

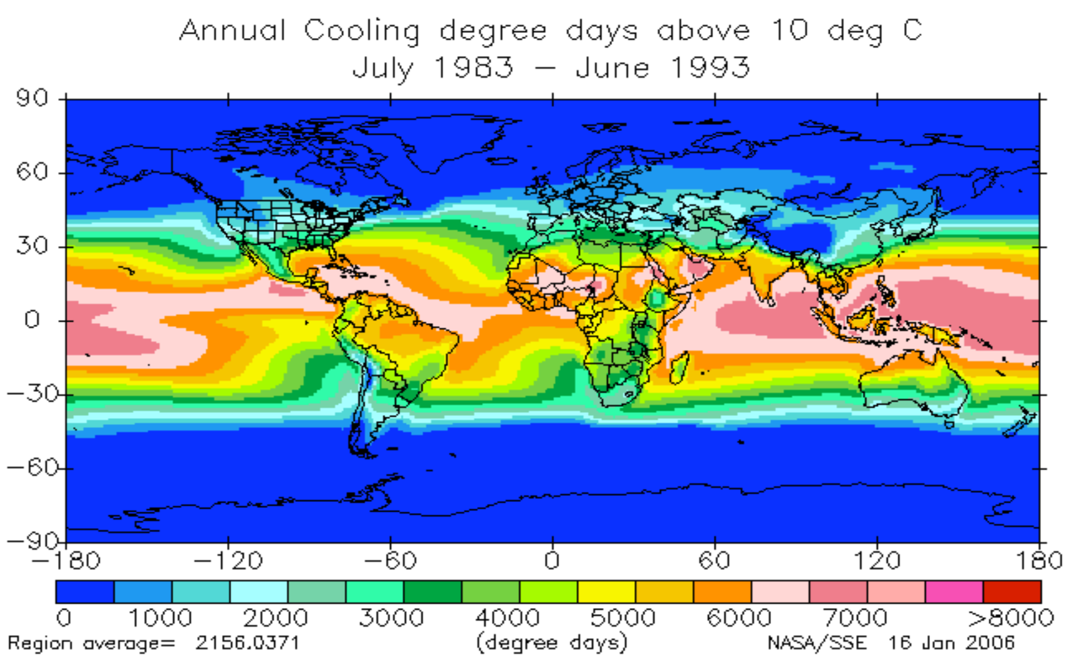


Figure 12. Release 5.1 SSE annual cooling degree days.

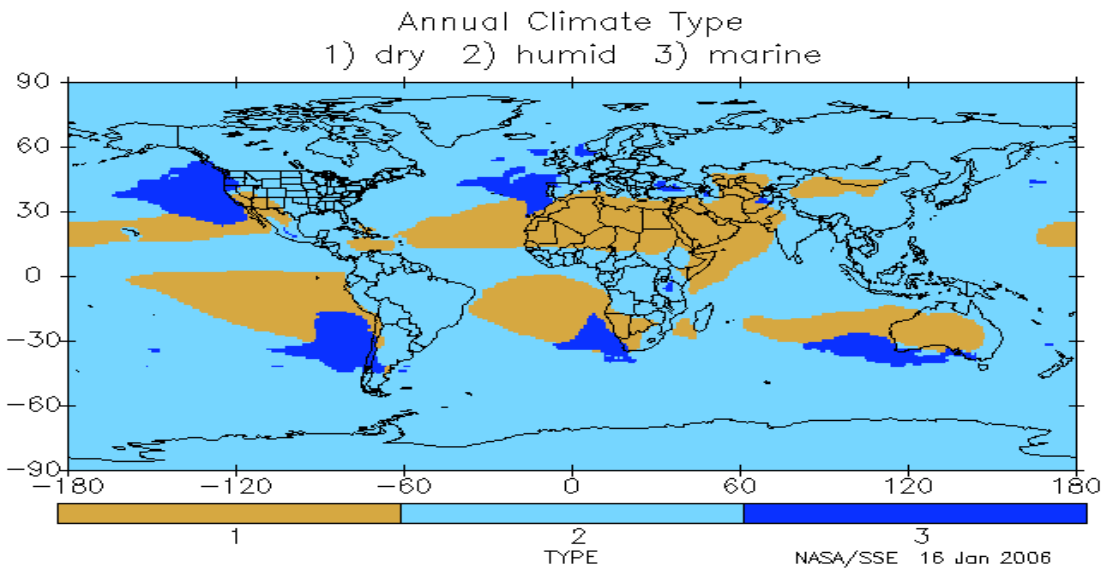


Figure 13. Preliminary moisture climate map after Briggs et al. (http://www.energycodes.gov).

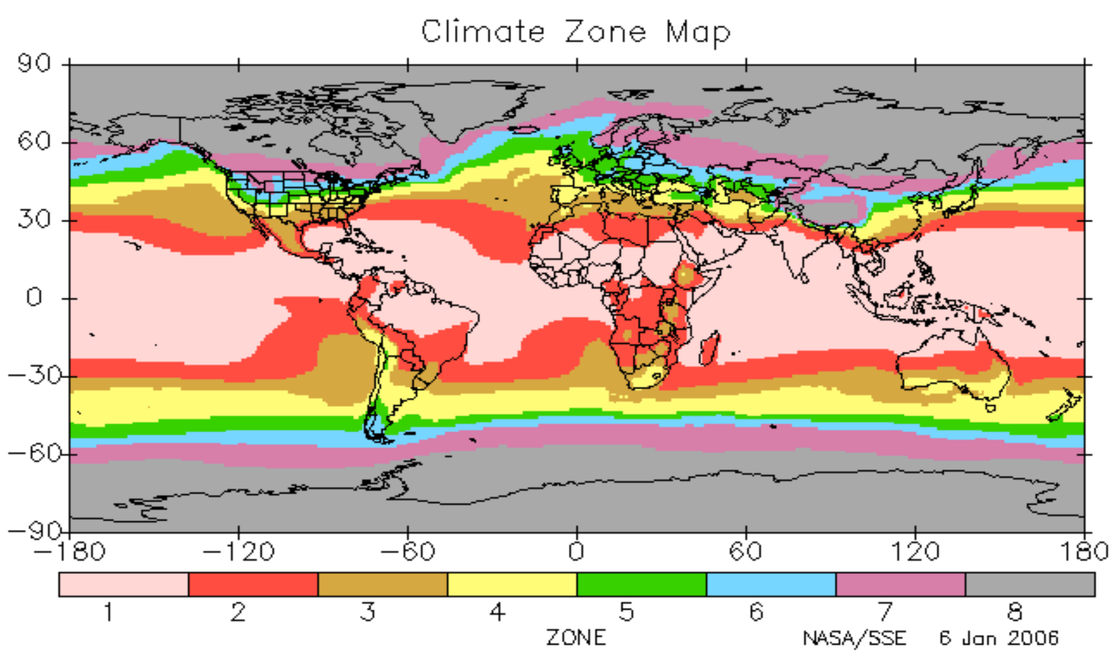


Figure 14. Preliminary buildings climate map after Briggs et al. (http://www.energycodes.gov).

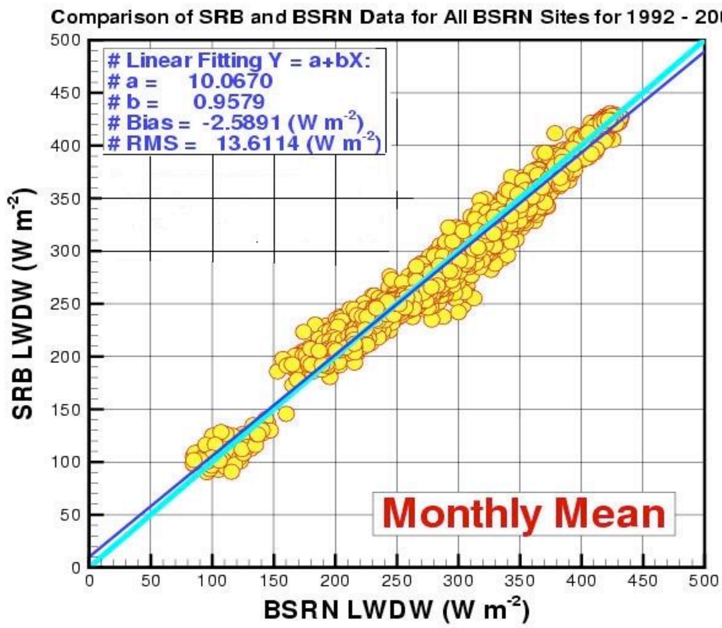


Figure 15. Comparison of future-Release SSE longwave downward (LWDW) surface radiation using new GEOS-4 meteorology as inputs plus correction for cell to site height differences.

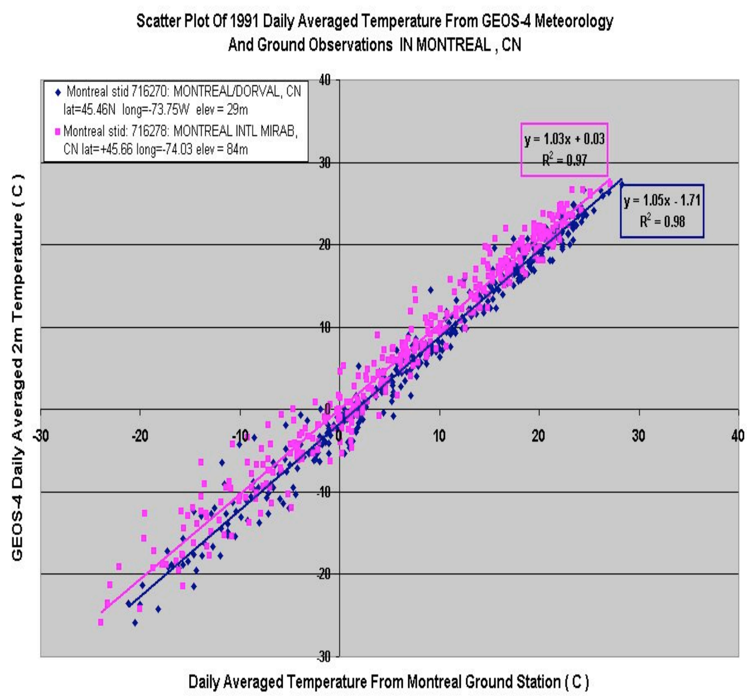
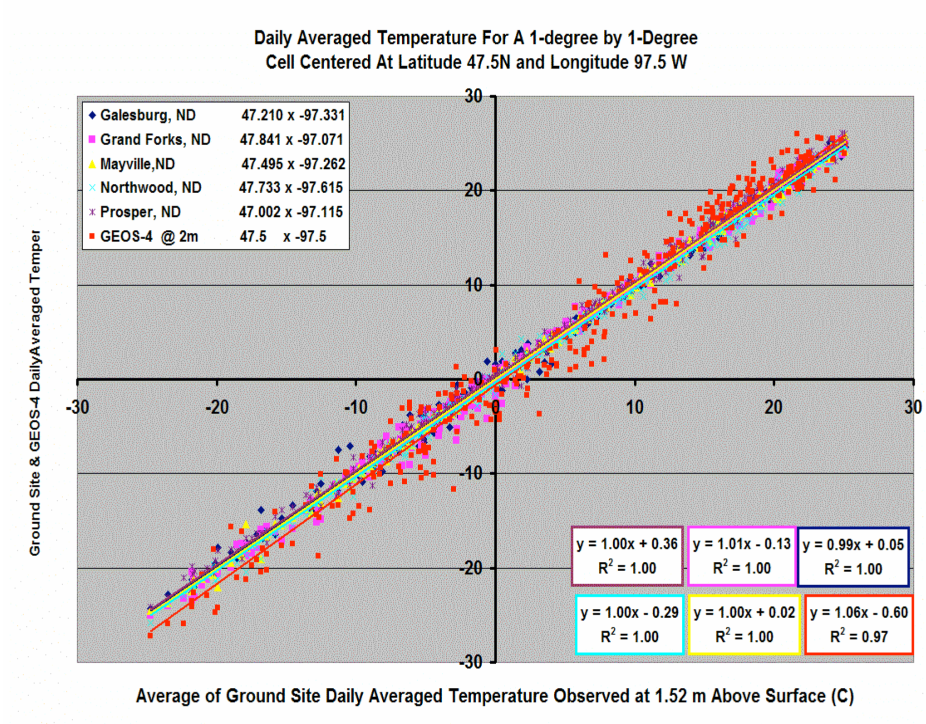


Figure 16. Initial GEOS-4 versus flat-terrain average city temperature comparison.



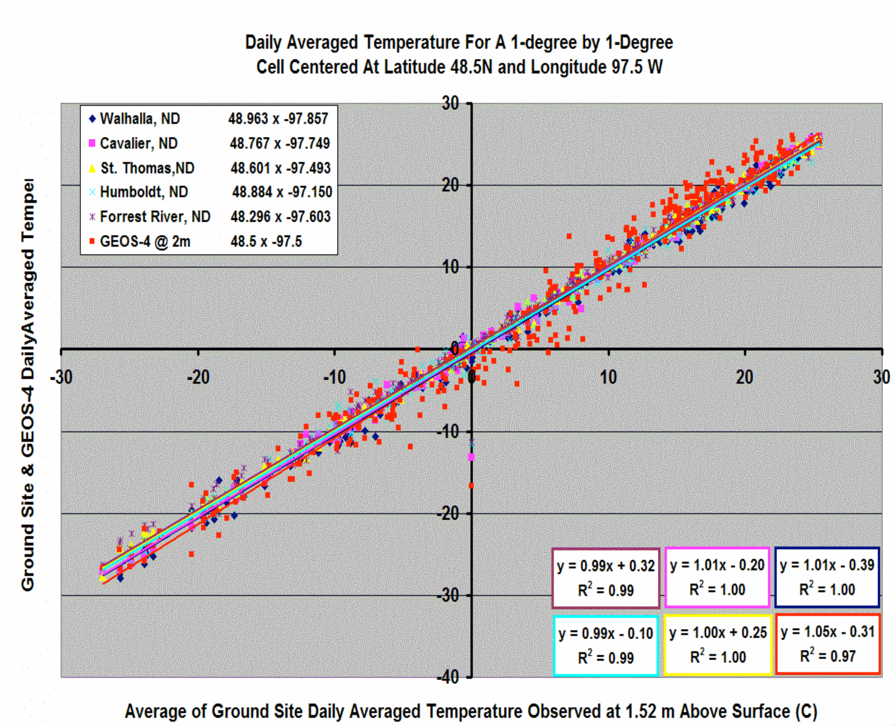


Figure 17. Initial GEOS-4 average temperatures comparison for flat-terrain sites in North Dakota.

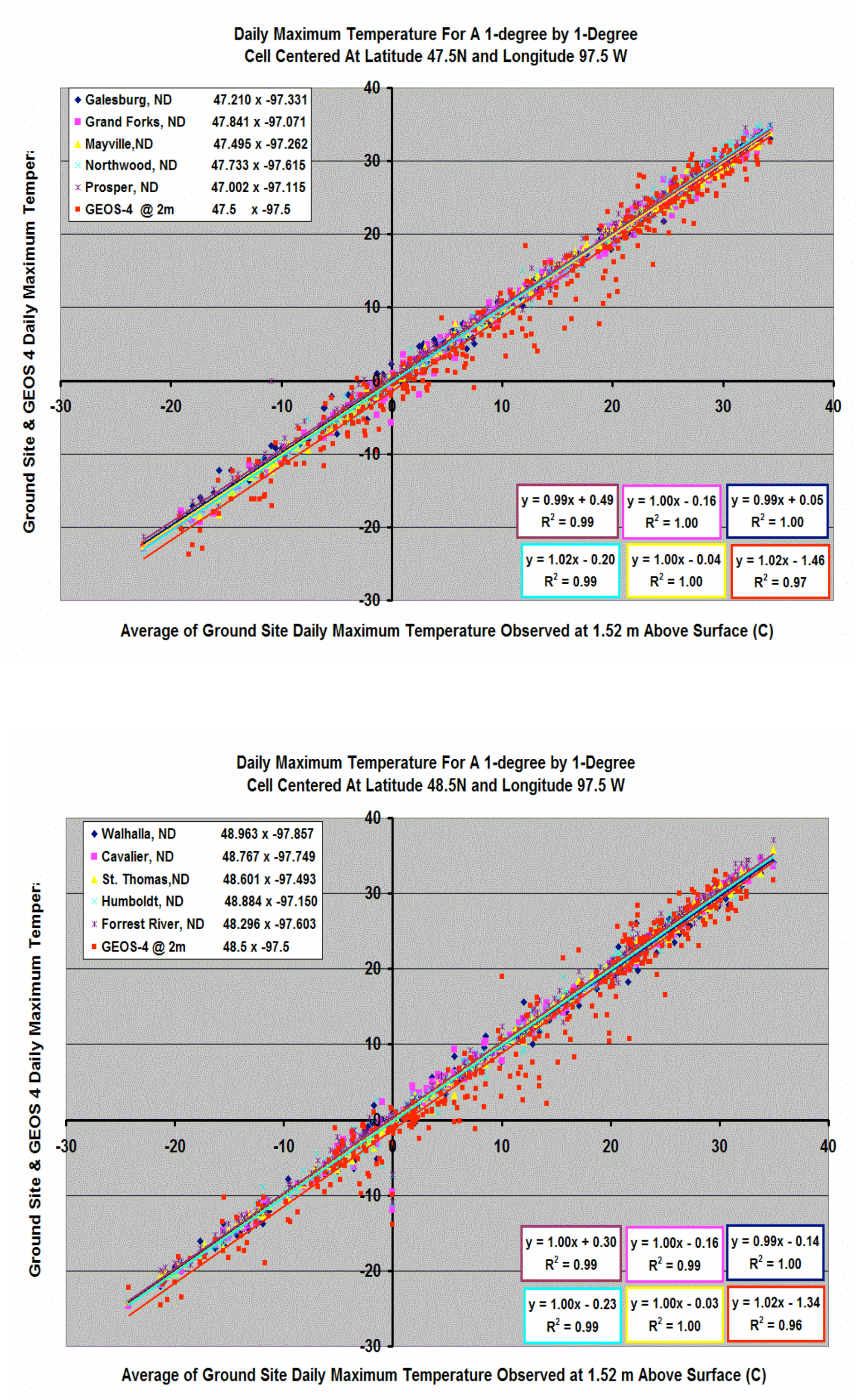
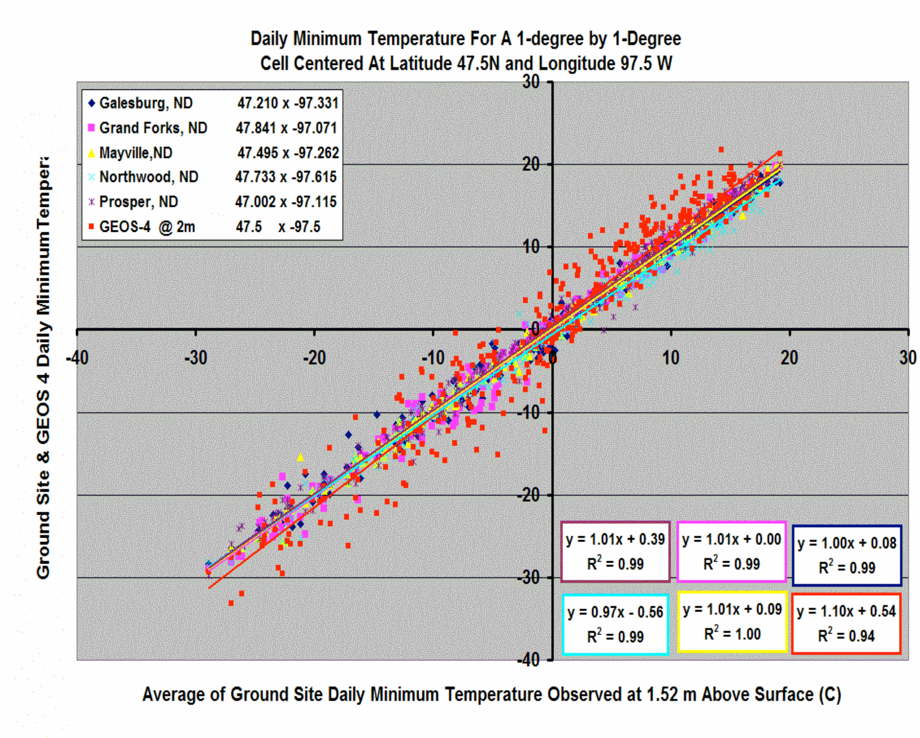


Figure 18. GEOS-4 maximum temperatures comparison for flat-terrain sites in North Dakota.



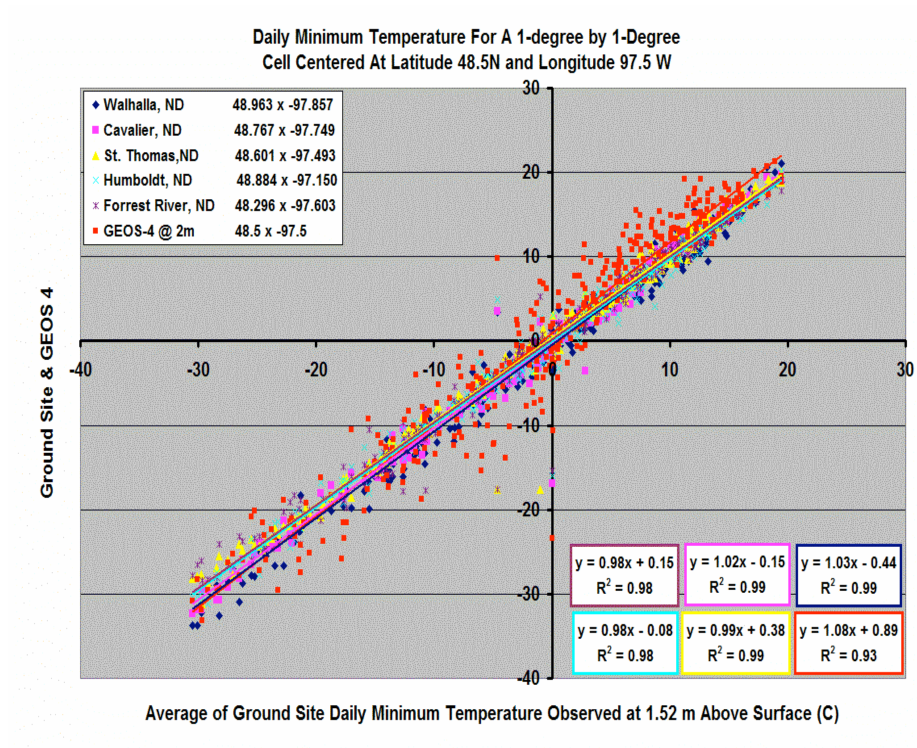
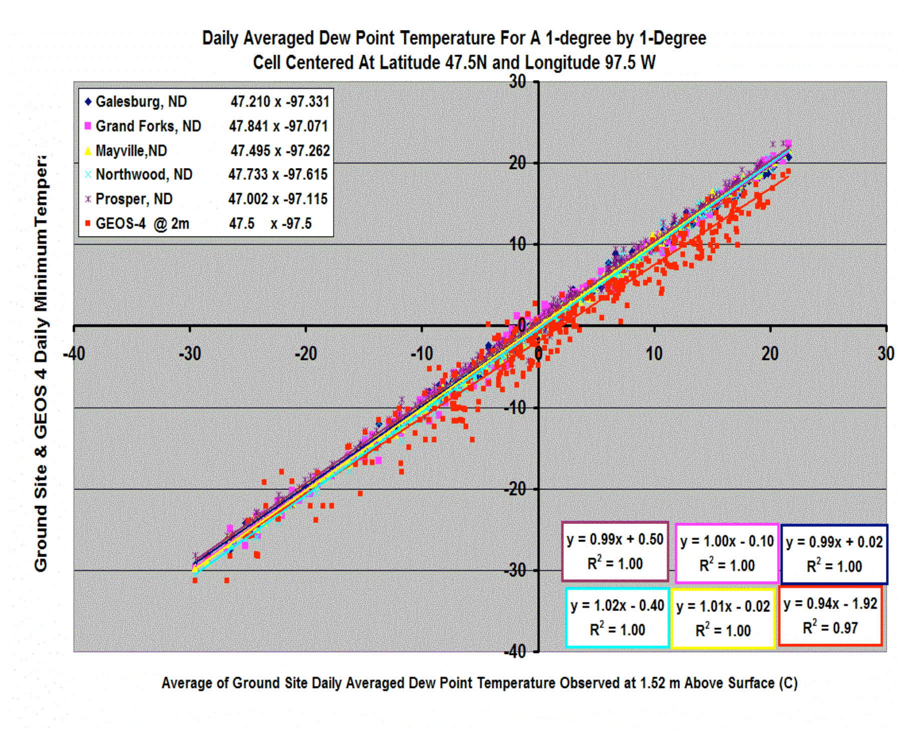


Figure 19. GEOS-4 minimum temperatures comparison for flat-terrain sites in North Dakota.



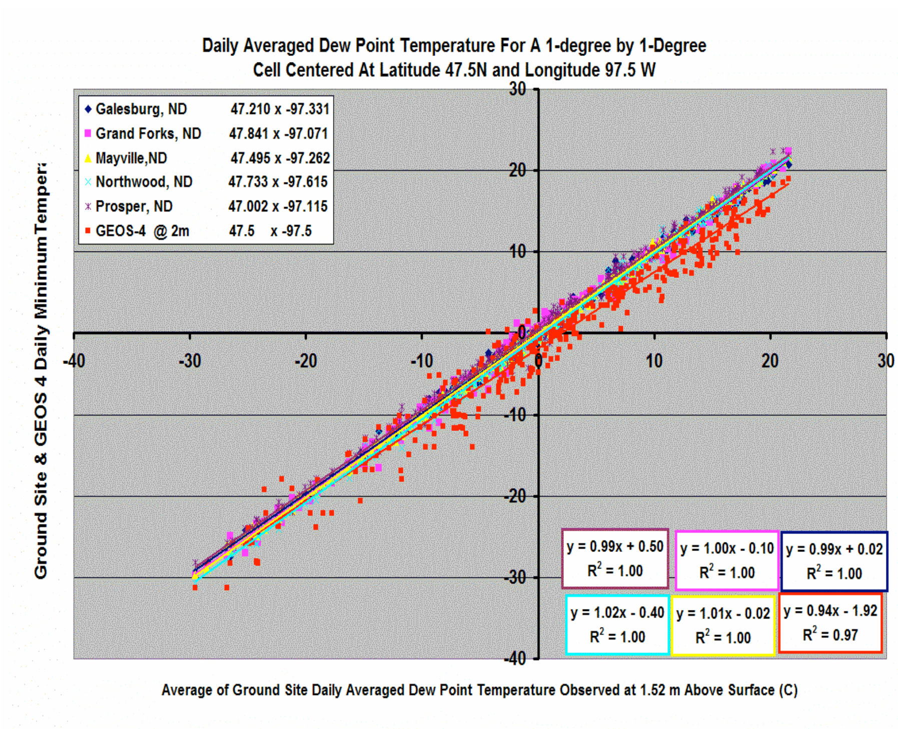


Figure 20. GEOS-4 dew point temperatures comparison for flat-terrain sites in North Dakota.

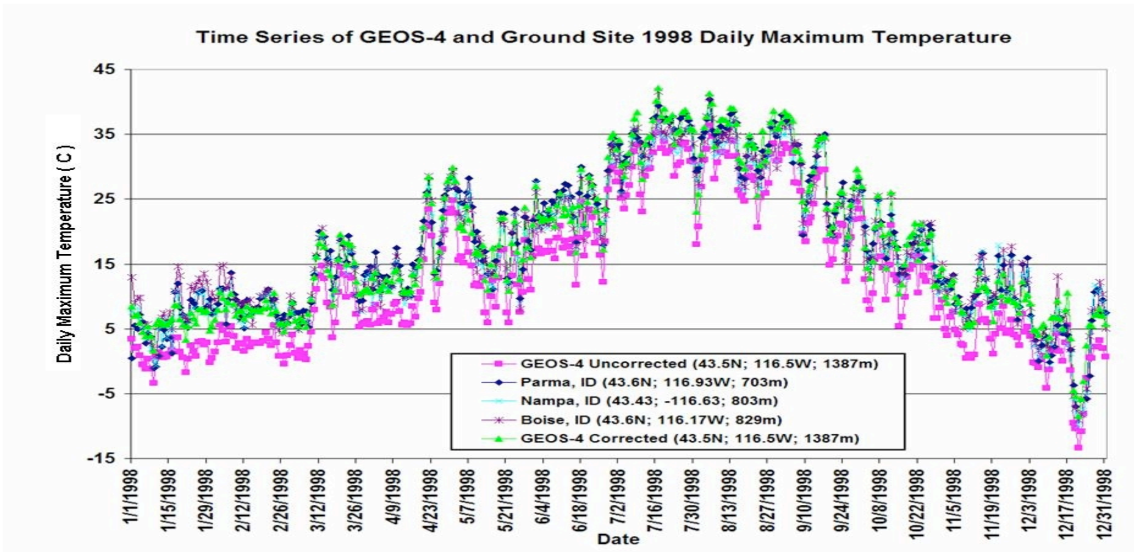


Figure 21. Lapse-rate-corrected GEOS-4 maximum temperatures for 3 sites at different altitudes within the same cell in mountain terrain.

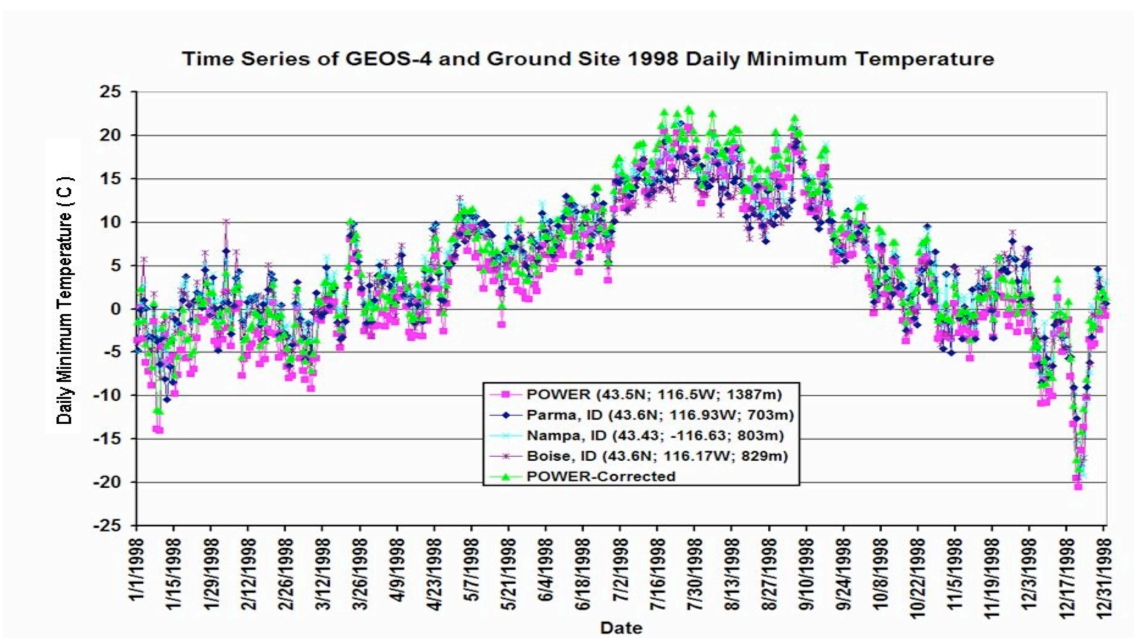
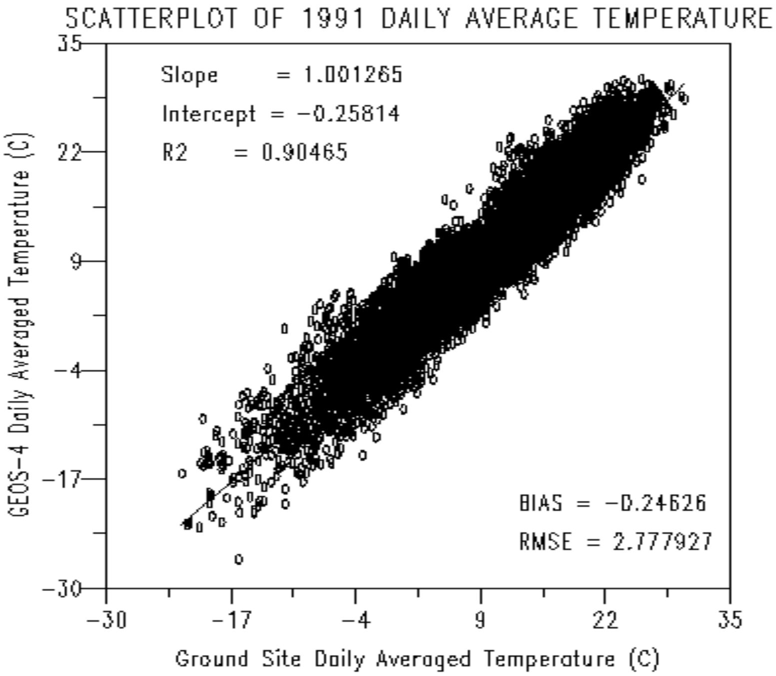


Figure 22. Lapse-rate-corrected GEOS-4 minimum temperatures for 3 sites at different altitudes within the same cell in mountain terrain.



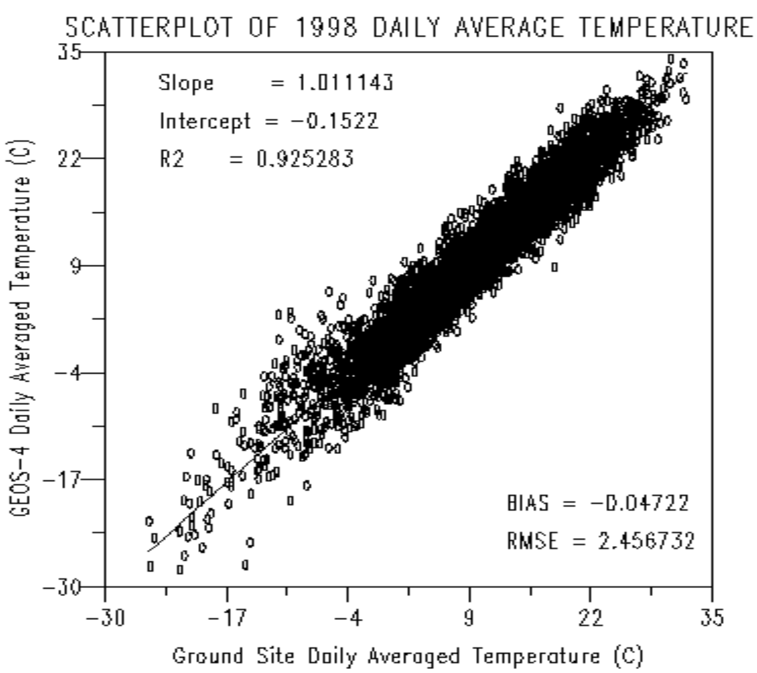
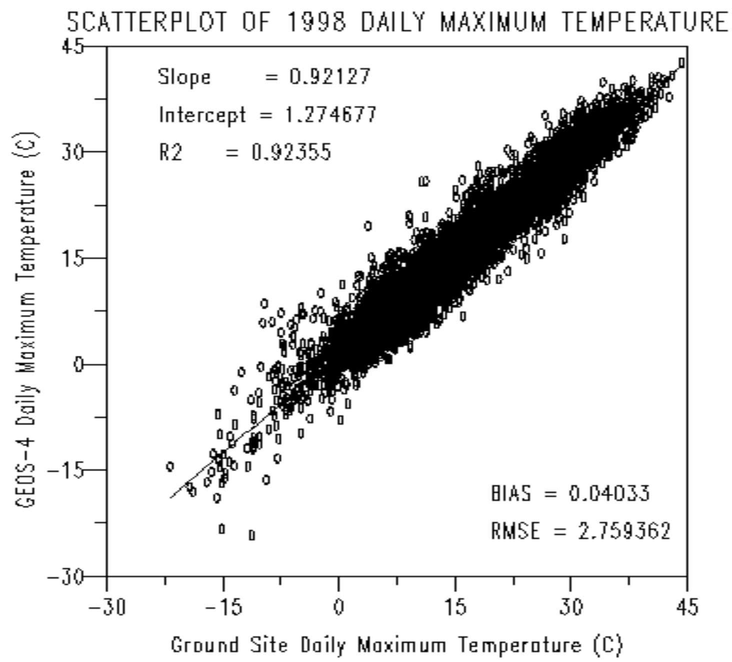


Figure 23. GEOS-4 to site comparisons for 1991 and 1998 daily average data in mountain terrain.



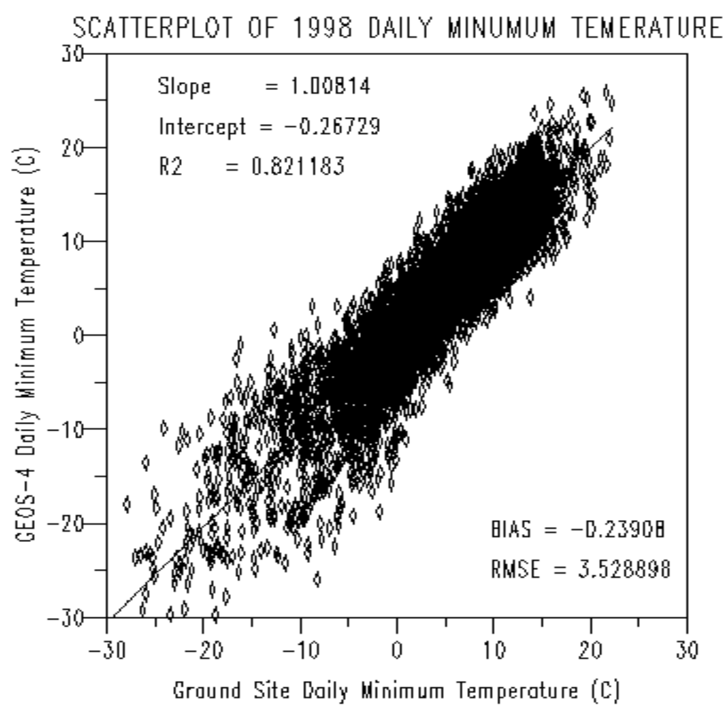


Figure 24. GEOS-4 to site comparisons for 1991 and 1998 daily maximum and minimum data in mountain terrain.